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EVALUATION OF SLIDE-TAPE LECTURE PROGRAMS USED IN AERO LABORATORIES

Frank Donald Schwikert

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THESIS

EVALUATION OF SLIDE-TAPE LECTURE PROGRAMS USED IN AERO LABORATORIES

by

Frank Donald Schwikert

March 1975

Thesis Advisor: R. D. Zucker

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Overcrowded conditions, unavoidable absence, and the lack of standardization in a course can detract from the learning experience.

In an attempt to solve these problems, fully automatic slide-tape programs have been developed for use in the gasdynamics laboratory course. A great deal of effort has gone into the development of these programs. In order to improve these lecture

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20. Abstract

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In general, the student reaction was favorable and indicated that a slide-tape program together with an appropriate handout would be sufficient to prepare students to conduct the experiments on a self-paced basis.

Also included in this thesis are an additional three slide-tape presentations entitled "Wind Tunnel Test Section Calibration", "Wind Tunnel Turbulence Calibration", and "Converging-Diverging Nozzles".

Evaluation of Slide-Tape Lecture Programs Used in Aero Laboratories

by

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Lieutenant, United States Navy
B.A.E., Georgia Institute of Technology, 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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I wish to thank my advisor, Associate Professor R. D. Zucker, for the assistance he has contributed toward this project. His technical expertise and attention to detail have been a great asset in the production of the slide-tape programs.

I also wish to credit both the graphics and photo divisions of the Educational Media Department at the Naval Postgraduate School for their assistance on special artwork and the development of new techniques for slide production.

I. INTRODUCTION

The Naval Postgraduate School gasdynamics laboratory course attempts to demonstrate basic fluid dynamics principles learned in the classroom. The procedures and specific experiments of this beginning laboratory course seldom vary. The briefing for such labs is ideally suited to some form of automation, and this is a necessary prerequisite if the laboratory courses are to be put on a self-paced format.

It is felt that any proposed automated briefing system should satisfy certain requirements. Specifically, it must be suitable for use by any number of students, be easy to produce and use, and be self-contained.

Some of the problems inherent in the teaching of a laboratory course were presented in a thesis entitled "Tape-Slide Lecture Packages for Use in Aero Laboratories," (Palka 1973). These include overcrowding of laboratory sections, improper briefing of students, the unavoidable absence of students or instructor, and non-standardization of the laboratory sessions.

In the thesis "Preparation of Slide-Tape Lecture Programs For Use in Aero Laboratories," (Wallace 1973) consideration was given to a number of different methods currently being employed by other schools in the instruction of laboratory courses. Among these were slide presentations, video tape systems, audio-tutorial systems, and instructional television.

The slide-tape presentation method was determined to most fully meet the requirements outlined above.

Initially the artwork for the slide-tape packages was produced entirely by the Educational Media Department of the Naval Postgraduate School. However, it was felt that time could be saved if the artwork was done by a student. If quality was preserved, this method of production could be used within the Aero Department. The follow on thesis by Wallace deals with the details of photographic and art slide production. The various machines and facilities available for student use are described in detail.

Seven slide-tape programs were produced by Palka and Wallace for use in the gasdynamics laboratory. These include:

1. Introduction to Low Speed Wind Tunnels
2. The Aerolab Low Speed Wind Tunnel
3. Operating Instructions for the Aerolab Tunnel
4. Wind Tunnel Balances
5. The Aerolab "543" Wind Tunnel Balance
6. Airfoil Performance by Pressure Distribution-Introduction
7. Airfoil Performance by Pressure Distribution-Data Reduction

This work is a continuation of the effort to prepare these fully automated slide-tape lecture packages.

II. OBJECTIVES

The main purpose of this project was to produce three slide-tape packages. Two of these supplement others already prepared for the low speed wind tunnel laboratory course. The final slide-tape presentation entitled "Converging-Diverging Nozzles" marks the first effort for an automated briefing in the compressible flow regime.

Another objective of this thesis was to develop a new questionnaire to sample student reaction to this form of presentation. Feedback is being sought on two questions: first, are the slide-tape programs sufficient preparation for self-paced labs, and second, what suggestions can the students make to improve the quality of the presentations?

III. EQUIPMENT

Slide-tape programs are presented with a Teaching Dynamics TD-201 audio-visual programmer connected to a Kodak Carousel remote controlled slide projector as shown in Figure 1. This system uses standard two-track cassette tapes.

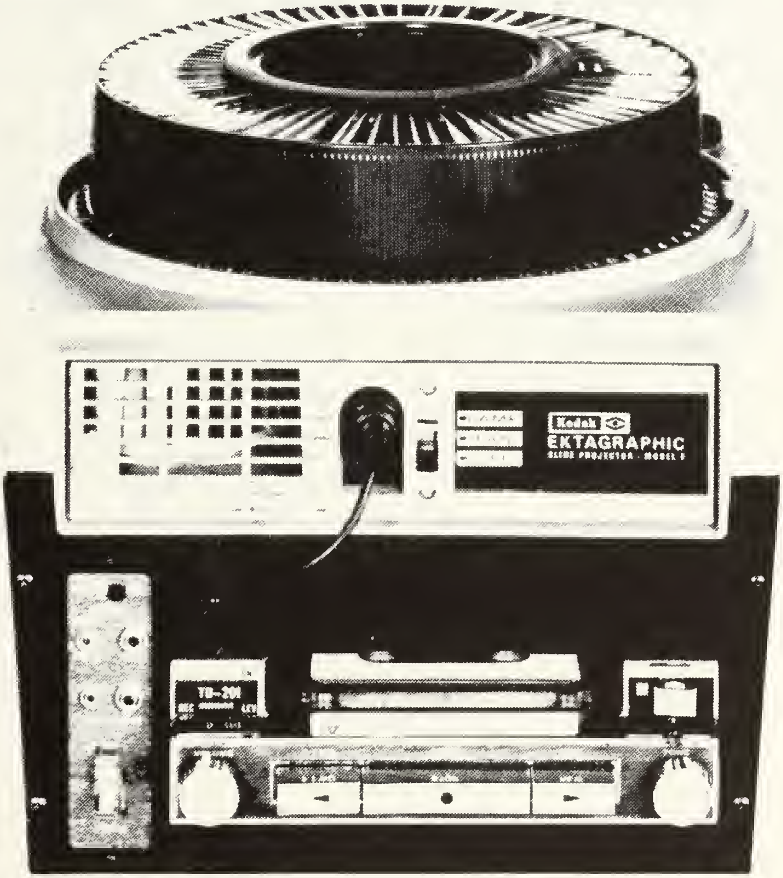

Figure 1.

The audio portion of the program is recorded on one track and the sound pulses for advancing the slides are recorded on the other track. The sound pulses have a duration of 0.5 seconds to 1.0 second and are recorded at a frequency of 120 Hertz. Further information concerning the TD-201 may be obtained by referring to the instruction manual.

Recently some difficulties have been experienced concerning the sound pulses. If these problems persist, an alternate means of presenting the slide-tape packages should be sought. It should also be pointed out that the frequency used by the Teaching Dynamics machine does not conform to the recently adopted standard. To be interchangeable with new machines, slide advance pulses should be 1000 Hertz and stop pulses (if used) should be 150 Hertz.

IV. PROCEDURE FOR PROGRAM PREPARATION

In planning any instructional sequence, it is important to first decide on specific objectives. Care should be taken to limit the objectives of each experiment to pertinent information. (Popham and Baker 1970) After all the information pertaining to the specific experiment is gathered, one can produce a detailed outline for the presentation. Next, simple sketch cards are prepared to illustrate important points. These sketches represent what will eventually become slides. Brief comments are then placed on the cards which aid in preparing the final script. A detailed script can now be written. This script is annotated for pulse positions which are numbered to correspond to the sequence of slides. Smooth artwork is then prepared for the sketch cards and 35mm slides used in the presentation are made from these drawings. Finally, the script is recorded along with the synchronization pulses which key advancement of the slide tray. Music, if desired, may also be incorporated into the program.

V. DEVELOPMENT OF A QUESTIONNAIRE

Previously, upon conclusion of the gasdynamics laboratory course, students were asked to fill out a questionnaire (Appendix D). This questionnaire attempted to sample student opinion on the effectiveness of the slide-tape form of presentation. It contained forced-choice questions of a general nature. Since it is anticipated that eventually the entire gasdynamics laboratory may be presented on a self-instructional basis, it was felt that a more detailed and carefully constructed questionnaire was needed. While the original questionnaire provided a format to judge student reaction to the slide-tape programs, it did not allow the student to critique the quality of the programs. Further, it did not solicit the students' assistance in refining existing lecture packages.

Care must be taken in developing any questionnaire that surveys opinion. A number of characteristics can degrade the validity of results (Payne 1973). Therefore in designing any questionnaire the following guidelines should be followed.

1. Question wording can influence the response. To assure that the intended issue is understood requires careful selection of wording.

2. Avoid misleading phrases or phrasing which does not affect the answer.

3. Dichotomous questions may be forcing respondents to choose where no choice exists, thus biasing the results. Offering a "No Opinion" reply will reduce this bias.

4. Free-answer questions provide the most uninfluenced results in sampling opinion.

5. Certain words are subject to variability in meaning. Words like "fair" and "good" leave too much room for interpretation and should be avoided. For a comprehensive list of such words, refer to "The Art of Asking Questions" (Payne 1973).

The original questionnaire (Appendix D) violates some of the guidelines listed above. The bulk of the questions are forced choice. This does not allow the student to fully express himself. Question six is worded too vaguely, it leaves too much to the students' interpretation. Question eight is worded in such a manner as to influence the response. In designing the new questionnaire (Appendix E) the above listed guidelines have been followed.

The worth of a questionnaire can be negated if the results are interpreted incorrectly. Three specific points to be used in evaluating the results obtained from any questionnaire are listed below.

1. Generally the worth of a question can be judged by the proportion of "No Opinion" replies.

2. Respondents are relatively free with their praise, and hesitant to criticize. Be prepared for low response to questions seeking criticism.

3. People ignore much of the detail that surrounds them. If a responder is asked to recall something, his reply should not necessarily be taken as fact.

VI. RESULTS

The three slide-tape programs resulting from this thesis are available through the Department of Aeronautics.

A. WIND TUNNEL TEST SECTION CALIBRATION

This presentation comprises a 14-minute audio tape and 51 35mm color slides (See Appendix A). The program discusses various calibration checks which must be made before a wind tunnel can be used. Since it is not possible to directly measure the test section velocity during an experiment, an indirect method is explained. The equation for the ideal velocity in the test section in terms of the pressure change across the contraction cone is developed, and the tunnel calibration factor and correction factor are defined. In addition, methods are described for measuring the lateral velocity profile and axial pressure gradient in the test section. This introductory program also suggests some organizational procedures to be followed while conducting the experiment.

B. WIND TUNNEL TURBULENCE CALIBRATION

This presentation comprises a 15-minute audio tape and 42 35mm color slides. (See Appendix B) Every wind tunnel has some degree of turbulence. In order to compare results obtained from different tunnels, a procedure has been developed to compensate for this turbulence by calculating

an "Effective Reynolds Number". To do this requires knowledge of the tunnel turbulence factor. This program discusses two methods for determining the turbulence factor with simple wind tunnel tests on a sphere. In order to explain the rationale behind these tests, it is desirable to review certain basic concepts. The program discusses laminar and turbulent boundary layer flow and the concept of flow separation. Typical drag curves of spheres are then related to the determination of the Turbulence Factor.

C. CONVERGING-DIVERGING NOZZLES

This presentation comprises a 13½-minute audio tape and 47 35mm color slides. (See Appendix C) This program is the first in the area of supersonic flow. The experiment provides the student with an opportunity to verify principles of gasdynamics learned in the classroom. First, varying-area isentropic flow is reviewed as it applies to a converging-diverging nozzle. Matched, overexpanded, and underexpanded flow regimes are then examined in some detail. This includes the formation of normal shock waves in nozzles as well as oblique shock and expansion waves outside the nozzle exit. Methods are suggested for measuring the Mach number of flow in a nozzle. A detailed description of the experimental apparatus is given, along with the various methods of measurement to be used. Two important real gas effects are mentioned as reasons for discrepancies between experimental results and theory.

D. RESULTS OF THE SLIDE-TAPE QUESTIONNAIRE

1. Original Questionnaire

The original questionnaire yielded information of a general nature. The exact breakdown of responses can be found on the copy included in Appendix D. The sample size was thirty-six students. Generally the students felt there was a need for a program of this type. The results indicated that the slide-tape format contributed to an understanding of the laboratory experiment and its objectives. A majority of the students felt they would be able to conduct the experiments on a self-paced basis with the use of the slide-tape programs and accompanying handouts.

2. Revised Questionnaire

The percentage responses to the revised questionnaire listed on the copy included in Appendix E are based on a sample size of twelve students. This questionnaire provided a clearer picture concerning the students' evaluation of the slide-tape program. The original questionnaire results indicated that the slide-tape format contributed to an understanding of the lab experiment and its objectives. This was reinforced by the revised questionnaire. However the results further indicated students unanimously felt the slide-tape programs were not sufficient preparation, and that the handouts were necessary.

Suggestions were made to include more pictures of the experimental set-ups in the programs. Results also indicated the organizational and procedural tips were of

great assistance to the students. They requested that similar tips be given in the area of data reduction.

Student opinion was also surveyed concerning the quality of the slide-tape programs. The majority of the students felt the length of the presentations and the number of slides used was sufficient. No preference was indicated concerning lettering/background color combination, although low contrast combinations such as black lettering on a red background were disliked. Some students felt that the slides sequenced too quickly, and that this detracted from the quality of the programs.

One half of the students showed a reluctance to give up an instructor during the experiment, although they all indicated they were capable of running the experiment on a self-paced basis.

Overall the slide-tape programs were well received. The students particularly liked the organized format and suggested that other labs be slide-tape formated.

VII. CONCLUSIONS AND RECOMMENDATIONS

From student surveys, it can be concluded that the slide-tape programs are contributing to an understanding of the laboratory experiments. The quality of existing packages is generally good. However, the written handout desired by the students for referral during the experiment could use improvement. (It should be noted that this particular group of students received an old "Lab Manual" which did not contain copies of two of the recently prepared programs.)

It is recommended that the remainder of the compressible flow portion of the gasdynamics laboratory be converted to slide-tape format. Each succeeding class should be surveyed to continually provide data to improve the packages. Questionnaires for this purpose should be handed out at the beginning of the course to allow each student to make pertinent comments as they occur. Finally, an attempt should be made at conducting the gasdynamics laboratory on a self-paced basis. If the results are satisfactory, then other laboratory courses should be converted to the slide-tape format.

APPENDIX A

WIND TUNNEL TEST SECTION CALIBRATION

1. (Start on blank slide -- no cueing pulse required. Background music on relatively loud.)

2. (Target slide.)

3. (Keep background music on at decreased volume.)

Building a new flight vehicle is preceded by a great deal of design and development work. This is particularly true when unconventional ideas are incorporated into the design.

4. The airflow around these intricate bodies is so complicated that even sophisticated mathematical modeling can predict only approximate performance parameters. To obtain more precise data one must resort to experimental methods using some type of wind tunnel.

5. Individual parts are normally tested first and then complete models are constructed and evaluated.

6. Meaningful results can only be obtained if the approaching airstream is well defined. Thus, before any experimental work can be carried out in a wind tunnel the test section must be carefully examined.

7. (Increase volume of background music. Slide on for max. of 5 secs.)

8. (After 3 secs. -- Fade out music.)

The calibration of a wind tunnel consists of investigating a number of factors.

9. First, the test section air speed must be determined . .

10. Knowledge of the exact wind velocity approaching the model permits accurate calculation of all important dimensionless performance parameters.

11. Next, the lateral velocity variation must be investigated . .

12. If large variations from a uniform velocity profile are found, changes must be made in the tunnel design.

13. The longitudinal pressure gradient should be checked . .

14. If the pressure changes significantly through the test section then all drag measurements must be corrected.

15. Flow angularity must also be checked . .

16. Flows which tend to rotate through the test section will introduce errors in all force and moment measurements.

17. The general turbulence level should be determined . .

18. High turbulence levels prohibit many types of tests. Even a small amount of turbulence modifies the "effective Reynolds number" used to compare test results from one tunnel with those of another.

19. This experiment deals only with determination of the test section air speed together with an investigation of the lateral velocity variation and the axial pressure gradient. Flow angularity and turbulence level will not be considered at this time. We will first discuss possible methods of checking tunnel air speed.

20. It is not practical to insert a pitot tube in the test section near the model. Its presence would interfere with the air flow around the model and lead to erroneous test results. Similarly, the velocity measured would not represent the velocity approaching the model.

21. One might suggest placing a pitot tube ahead of the model at the entrance to the test section. However, such a tube must be located rather close to the wall in order not to affect the air flow over the model.

22. Such a location places the pitot tube in the region of the boundary layer where the velocity measured is not that of the free airstream.

23. In most wind tunnels we resort to an indirect measurement of tunnel air speed. This is done by correlating the pressure change across the contraction cone to the velocity in the test section . . Let us examine how these are related.

24. We first write an energy equation between the inlet to the contraction cone and the inlet to the test section. Since the tunnel operates at relatively low speeds we use the equation in a form valid for incompressible flow . . .

25. Changes in potential are neglected, and we also note that no shaft work is involved between the two stations. The last term, h_f, represents the losses in the contraction cone. We consider the ideal case by neglecting these losses . .

26. The terms of this equation are easily rearranged to give the pressure change, $p_1 - p_2$, in terms of the velocities at stations one and two . . .

27. We now introduce the continuity equation . . simplify it for incompressible flow, and obtain the familiar expression for the velocity ratio in terms of the area ratio . . .

28. Substitution of the results from the continuity equation into the energy equation enables one to solve for the ideal velocity at section two in terms of the pressure change across the contraction cone and the tunnel area ratio . . . This equation can also be squared and rearranged to obtain an expression for the dynamic pressure, ρV^2 over $2g_c$.

29. The dynamic pressure in the test section is normally referred to as the tunnel "q". Here we see that the ideal q is directly related to the measured Δp and the tunnel geometry. For most tunnels the square of the area ratio is negligible. Thus the constant indicated is approximately unity . . Note that this expression represents the ideal tunnel q. The actual q will be slightly different due to the viscous and three-dimensional effects that were neglected. However, the expression indicates that the final calibration between Δp and q should be essentially linear.

30. The actual tunnel q is measured with a calibrated pitot tube which is placed in the center of the test section . .

31. The difference between the total and static pressure indicated by the pitot tube directly represents the tunnel q . .

32. Piezometer rings, which have taps on all four walls of the tunnel, enable average pressures to be detected at stations one and two. Thus, the required Δp and the true q can easily be measured by two differential micromanometers.

33. A calibration curve is obtained by plotting Δp versus q true . .

34. In most cases this curve is linear and its slope is called the tunnel calibration factor . .

35. The ratio of the true q to the ideal q is known as the "q correction factor." Recall that the constant in q ideal is very close to unity; thus the q correction factor is approximately the reciprocal of the tunnel calibration factor.

36. Having completed our discussion of the speed calibration we now turn to an examination of the lateral velocity variation.

37. Ideally, the velocity profile should be constant across the test section. Boundary layer effects are normally quite small immediately following a contracting section.

38. By traversing the test section with a pitot tube, the actual velocity profile can easily be determined.

39. It is possible that imperfections in design or construction of the tunnel have caused significant deviations from the desired velocity profile. If so, this must be remedied by introducing guide vanes and/or screens ahead of the test section.

40. Finally, let us examine the axial pressure distribution.

41. If the walls of the test section are parallel, the thickening boundary layer tends to produce an effective contraction. This causes the free stream velocity to increase as it passes through the test section with a corresponding decrease in pressure. Such a pressure gradient would introduce an erroneous drag force on any model being tested.

42. All well designed wind tunnels avoid this problem by having diverging walls which present a gradually increasing cross-section to the air as it passes through the test section. However, this is usually only effective over a small range of tunnel speeds.

43. Pressure ports located at the bottom wall of the test section are used for checking the axial pressure gradient.

44. Flexible tubing connects each port to the top of a manometer. A common reservoir feeds the entire bank of manometers.

45. One of the manometer tubes is left open to the atmosphere. It is essential to realize that the height of any liquid column means nothing by itself, only the difference above or below the atmospheric column is significant. Also, since the tubes are attached to the top of the board, the higher liquid columns indicate lower pressures . .

46. The axial pressure distribution is vividly displayed on the manometer board . .

47. Before you enter the laboratory you should carefully study the written handout. Be familiar with the calculations that must be made so that you know what data to take. When you fully understand the experiment, examine the laboratory set-up. Considerable time can be saved by becoming thoroughly familiar with the equipment.

48. Design a data sheet before starting the tunnel. This sheet should not only contain an appropriate title together with any additional information taken at the time of the experiment such as date, tunnel operating data, atmospheric temperature and pressure, etc. Be sure to include the units for all measurements.

49. Carefully distribute the workload among the members of your laboratory group. If excess labor is available results can be calculated and working plots made while you are running the experiment. Bad data points can easily be spotted by this procedure.

50. Check all instruments to make sure they are properly zeroed. When you are satisfied that everything is in order, start the experiment.

51. In summary, we have mentioned the various calibration checks that must be made before one can use a wind tunnel to obtain meaningful test data. Three of these have been discussed in detail. These are determination of the speed calibration . . investigation of the lateral velocity variation . . and a check on the axial pressure gradient. Some helpful suggestions were also made on organizational procedures to be followed prior to running the experiment.

(Start background music.)

52. (Schwikert - Zorro Production slide)

53. (Blank -- Continue music.)

WIND TUNNEL TEST SECTION CALIBRATION

Slide List

1. Blank.
2. Target Slide.
3. Artist Drawing of XFV-12A in Flight.
4. Artist Drawing of XFV-12A Landing.
5. Photo of a Wing in the Wind Tunnel.
6. Photo of Complete Aircraft in the Wind Tunnel.
7. "The Department of Aeronautics Presents."
8. "Wind Tunnel Test Section Calibration."
9. "Test Section Calibration" plus "Speed Setting."
10. Model in Tunnel with oncoming Velocity.
11. Same as Slide #9 plus "Lateral Velocity Variation."
12. Lateral Velocity Variation Profile.
13. Same as Slide #11 plus "Longitudinal Pressure Gradient."
14. Wind Tunnel with Pressure Guages distributed Axially along Tunnel.
15. Same as Slide #13 plus "Flow Angularity."
16. Angular Flow in the Wind Tunnel.
17. Same as Slide #15 plus "Turbulence Level."
18. Tunnel with Turbulent Flow in it.
19. Summary of Objectives.
20. Photo showing Pitot Tube right next to Model.
21. Diagram of Wind Tunnel showing Pitot Static Tube.
22. Photo of Pitot Static Tube in Tunnel Wall.
23. Diagram of Contraction Cone and Test Section showing Δp and V.

24. Energy Equation.

25. Energy Equation with Terms crossed out.

26. Energy Equation rearranged to show $p_1 - p_2$.

27. Continuity Equation.

28. Equation for V_{2ideal}.

29. Equation for q_{ideal}.

30. Photo of Pitot Static Tube mounted in Test Section.

31. Equation for q_{true}.

32. Diagram of Tunnel showing Δp and q_{true}.

33. Plot of Δp_{1-2} vs q_{test}.

34. Definition of Tunnel Calibration Factor.

35. Definition of q Correction Factor.

36. "Lateral Velocity Variation."

37. Diagram of Ideal Velocity Profile in Test Section.

38. Photo of Pitot Static Tube and Transversing Mechanism.

39. Same as Slide #12.

40. "Axial Pressure Gradient."

41. Diagram of Tunnel with Constricted Flow from Parallel Walls.

42. Diagram of Tunnel with Diverging Walls.

43. Photo of Pressure Taps in the Tunnel Floor.

44. Photo of Tubing leading from the Pressure Taps in Tunnel Floor.

45. Diagram of Manometer Tubes showing Δh.

46. Photo of Manometer Board showing Axial Pressure Distribution.

47. "Procedures."

48. Data Sheet.

49. Photo showing One Man reading Micromanometer, another Operating Speed Controls.

50. Photo showing Man checking Zero on the Micromanometer.

51. Summary.

52. "A Schwikert-Zorro Production."

53. Blank.

APPENDIX B

WIND TUNNEL TURBULENCE CALIBRATION

1. (Start on blank slide - no cueing pulse required. Background music.)

2. (Target slide.)

3. (Department of Aeronautics Presents.)

4. (Wind Tunnel Turbulence Calibration - Fade out music.)

5. Early wind tunnel experiments revealed discrepancies among test results of similar bodies when run in different wind tunnels. Investigations showed that these discrepancies were caused by varying degrees of turbulence produced in each tunnel. A procedure has been developed to compensate for this turbulence by calculating an "Effective Reynolds Number". This permits data from different wind tunnels to be compared in a consistent manner.

6. This presentation will discuss how the Effective Reynolds Number is computed through the use of a "Tunnel Turbulence Factor" and how the turbulence factor is determined with simple tests in a wind tunnel.

7. In order to explain the rationale behind these tests, it will be necessary to review some boundary layer concepts, including the different velocity profiles typical of laminar and turbulent flow.

8. This will lead to a discussion of boundary layer "separation" which dramatically affects the drag coefficients of typical bodies.

9. The turbulence associated with flow in the test section of a wind tunnel causes flow conditions to be similar to those that would occur if the same object were tested in free air at a higher Reynolds number. Thus, if the calculated test Reynolds number is multiplied by an appropriate Tunnel Turbulence Factor an Effective Reynolds number is computed which represents comparable free stream conditions.

10. Each wind tunnel has a Turbulence Factor which is determined by its design and construction. This factor changes slightly with tunnel speed but is nearly constant for each tunnel. Turbulence Factors range from one to three with a value of less than 1.4 required to obtain good test results.

11. If we take the test results that were shown previously, and in each case multiply the test Reynolds number by the turbulence factor appropriate for that tunnel, the results can be plotted against Effective Reynolds number.

12. When this is done, we see that the test results obtained in three different tunnels are in close agreement with one another.

13. To understand how the Turbulence Factor is determined we must first digress to discuss a few concepts from boundary layer theory.

14. When a fluid with a uniform velocity passes over a solid boundary the particles of fluid next to the wall are brought to rest. This viscous effect propagates outward to produce a velocity profile which varies from zero at the wall to the free stream velocity a short distance away from the wall.

15. The region close to the wall where these significant viscous effects occur is called the "boundary layer". The exact shape of the velocity profile within the boundary layer depends on the flow regime involved.

16. At low Reynolds numbers - where the viscous forces predominate - the fluid tends to flow in layers without any energy exchange between adjacent layers. This is termed "laminar flow" and the velocity profile is parabolic.

17. At high Reynolds numbers the large inertia forces cause irregular velocity fluctuations in all directions which in turn cause mixing between adjacent layers. This mixing transfers energy to the fluid particles next to the wall and increases their velocity. This is a typical "turbulent flow" velocity profile.

18. Thus we see that for the same free stream velocity and the same boundary layer thickness, laminar and turbulent velocity profiles are radically different. We shall soon see that this difference plays an important part in explaining the characteristic shape of drag curves.

19. Before we can complete our story we must briefly discuss the phenomena of "boundary layer separation".

20. As fluid flows around an object the pressure first decreases as the velocity increases. However, over the rear portion of the object the pressure increases again as the fluid velocity decreases. It is in this latter region that problems occur.

21. Here we see a fluid particle under the influence of this type of pressure field. It is called an "adverse pressure

gradient" since these forces cause a fluid particle next to the wall to decelerate and eventually reach a condition of reverse flow. At this point the boundary layer is said to "separate" from the wall and a region of great turbulence exists between the boundary layer and the wall.

22. Now recall the possible velocity profiles that can exist within a boundary layer. It should not be difficult to realize that a laminar profile would be relatively easy to slow down and separate as the particles close to the wall contain little kinetic energy to begin with. In contrast to this is a turbulent profile which tends to resist separation for a much longer time.

23. Here we see a sphere at low Reynolds number with a completely laminar boundary layer. Separation occurs aft, but very near the maximum thickness point of the body. Consequently a very large wake forms which prevents normal pressure recovery behind the sphere and a large pressure drag exists.

24. In this picture we see the same sphere at a higher Reynolds number. In this case the boundary layer is turbulent and it tends to resist separation until much farther aft on the sphere. This results in a smaller wake with a correspondingly reduced pressure drag.

25. We can now look at the complete drag curve for a sphere and understand the reasons for its characteristic shape. At low Reynolds numbers the laminar boundary layer permits early separation, large wakes, and high drag coefficients. When the separation point becomes stabilized the drag coefficient remains constant. As the Reynolds number increases the character of the boundary layer changes.

26. Somewhere on the surface of the sphere the laminar boundary layer will transition to a turbulent one which separates much farther aft. The smaller wake produces a dramatic drop in the drag coefficient. The Reynolds Number at which this transition occurs is on the order of 3×10^5. The exact number is a function of the freestream turbulence and thus this characteristic curve can be used to determine the Tunnel Turbulence Factor.

27. By taking force measurements on a sphere in a wind tunnel, drag coefficients may be computed and plotted against Reynolds number. The Reynolds number for which the drag coefficient equals .3 is called the "Critical Reynolds Number."

28. If a sphere were tested in turbulent free air, the critical Reynolds number would be exactly 385,000.

29. Thus the turbulence factor for any particular tunnel can easily be calculated by a ratio of 385,000 to the critical Reynolds number noted for that tunnel.

30. Although this procedure appears to be straightforward and simple it is frequently difficult to accurately determine the support tare drag and thus we seek an alternate method to determine the critical Reynolds number.

31. This second method makes use of pressure taps located on the surface of a sphere. One orifice is located at the forward stagnation point.

32. Four other orifices are located 22½° off the longitudinal axis near the rear of the sphere. These four taps are connected together to yield an average pressure.

33. The pressure difference is noted between the forward and rear taps. This Δp is corrected for any logitudinal test section pressure gradient that may exist, then divided by the tunnel dynamic pressure, and plotted against Reynolds number.

34. It has been found experimentally that when Δp over q equals 1.22, the drag coefficient of the sphere is .3. Hence this plot can be used to determine the critical Reynolds number of the tunnel.

35. The Turbulence Factor is calculated as indicated previously by dividing the critical Reynolds number into 385,000.

36. While you are running this experiment you may also be asked to investigate the pressure distribution over the entire surface of the sphere. This can easily be done, since there are 15 additional pressure taps on the sphere whose exact locations are given in a separate handout.

37. When connected to a manometer board the pressure distribution is visually displayed and the separation point can be easily noted.

38. Prior to conducting this experiment you should carefully study the written handout. Be familiar with any calculations that must be made so that you know what data to take. When you fully understand the experiment go to the laboratory and examine the experimental set-up. Becoming familiar with the equipment prior to running the experiment can save considerable time.

39. Prepare a data sheet before starting the tunnel. This sheet should not only contain columns for all data taken for each run, but also should contain an appropriate title

together with any additional information taken at the time of the experiment such as the date, tunnel operating data, atmospheric temperature and pressure, etc. Be sure to include the units for all measurements.

40. Check all instruments to make sure they are properly hooked up and zeroed. When you are satisfied that everything is in order, start the experiment.

41. Carefully distribute the workload among the members of your laboratory group. If excess labor is available, results should be calculated and working plots made while you are running the experiment. Bad data points can easily be spotted by this procedure.

42. In summary, we have seen the importance of knowing tunnel turbulence factors in order to compare data obtained in different wind tunnels. Boundary layer theory and the phenomena of separation have been discussed briefly in order to explain how simple tests on a sphere can be used to determine the tunnel turbulence factor. Finally, some helpful suggestions were made on organizational procedures to be followed prior to running the experiment.

(Start background music.)

43. (Schwikert - Zorro Production slide.)

44. (Blank --- Continue music.)

WIND TUNNEL TURBULENCE CALIBRATION

Slide List

1. Blank.
2. Target Slide.
3. "The Department of Aeronautics Presents."
4. "Wind Tunnel Turbulence Calibration."
5. Plot of C_D vs Test Reynolds Number for Three Tunnels.
6. "Turbulence Calibration" plus "Turbulence Factor."
7. Same as Slide #6 plus "Boundary Layer Concepts."
8. Same as Slide #7 plus "Separation."
9. Effective Reynolds Number defined.
10. Some Facts about Tunnel Turbulence Factor.
11. Plot of C_D vs. Reynolds Number showing Test and Effective Point.
12. Plot of C_D vs Effective Reynolds Number showing Points from Three Different Tunnels coinciding.
13. "Boundary Layer Theory."
14. Sketch of Uniform Velocity transversing a Wall and forming a Boundary Layer.
15. Sketch of Velocity Profiles within a Boundary Layer.
16. Sketch of Laminar Boundary Layer Velocity Profile.
17. Sketch of Turbulent Boundary Layer Velocity Profile.
18. Sketch showing both Laminar and Turbulent Velocity Profile.
19. "Separation."
20. Sketch of Flow over an Object showing Pressure Regions.
21. Sketch of Velocity Profile developing Separation.
22. Same as Slide #18.

23. Sketch of Laminar Flow around a Sphere.

24. Sketch of Turbulent Flow around a Sphere.

25. Plot of C_D vs Reynolds Number pointing out Region with Laminar Boundary Layer.

26. Plot of C_D vs Reynolds Number pointing out Region with Turbulent Boundary Layer.

27. Plot of C_D vs Reynolds Number at R_{crit} in Tunnel.

28. Plot of C_D vs Reynolds Number at R=385,000 in Free Air.

29. Calculation of Tunnel Turbulence Factor.

30. Sketch of Sphere in Tunnel showing Sphere and Support Tare Drag.

31. Photo showing Stagnation Point on Test Sphere.

32. Photo showing Aft Taps on Test Sphere.

33. Definition of Δp on Test Sphere.

34. Plot of $\Delta p/q$ vs Reynolds Number in the Area of R_{crit}.

35. Tunnel Turbulence Factor calculation.

36. Photo of Test Sphere showing Pressure Taps from front to rear.

37. Photo of Manometer Board showing Separation.

38. "Procedures."

39. Data Sheet.

40. Photo of Man checking Manometer Tubing.

41. Photo showing Two Men plotting and calculating.

42. Summary.

43. "A Schwikert-Zorro Production."

44. Blank.

APPENDIX C

CONVERGING - DIVERGING NOZZLES

1. (Start on blank slide . . . no cueing pulse required. Background music on relatively loud.)

2. (Target slide.)

3. (Keep background music on at decreased volume.)

One of the topics of your gasdynamics course is varying area adiabatic flow. During these studies you learn that in order to produce a supersonic stream it is necessary to have a flow passage whose area first decreases - and then increases.

4. However, area changes alone cannot guarantee supersonic flow; the proper pressure conditions must exist at entrance and exit.

5. Otherwise peculiar flow conditions may result at the exit or even inside the device.

6. (Increase volume of background music.)

7. (Fade out music.)

8. In this presentation we shall review the operating regimes of converging-diverging nozzles. Your experimental work will verify the various modes that are predicted by theory. You will also have a chance to determine Mach numbers by several methods.

9. We start with a converging-diverging nozzle of fixed geometry. This type of nozzle is physically distinguished by its area ratio; that is, the ratio of the exit area A_e to the minimum or throat area A_t.

10. The pressure conditions that exist at entrance and exit go along with the area ratio to determine the mode of operation. Specifically, we are interested in the stagnation - or total pressure feeding the inlet, and the static pressure in the receiver that is sensed by the outlet.

11. We frequently plot the pressure distribution throughout the nozzle. For convenience all pressures are ratioed to the inlet stagnation. In this plot we show the receiver pressure the same as the inlet - and obviously no flow occurs.

12. As the receiver pressure is lowered, flow is initiated. At first velocities are all subsonic and typical venturi operation results. Minimum pressure and maximum velocity exists at the throat.

13. As the receiver pressure is lowered still further, the flow rate increases; also pressures lower and the velocities increase throughout the device.

14. Eventually, we reach sonic velocity at the throat and the nozzle is said to be "choked", as we have reached a maximum flow rate for any given inlet condition. Note that subsonic flow still exists in both the converging and diverging sections. This condition is sometimes called the "first critical point."

15. The objective of this device is to produce supersonic flow. But we find that to do this we must lower the receiver pressure to a very low value. Conditions up to the throat have not changed - hence the flow rate is the same. But now the entire diverging section contains supersonic flow. This condition is referred to as "third critical." A question naturally arises concerning what happens with the vast range of receiver pressures between 1st and 3rd critical.

16. Here the receiver pressure is set slightly below that required for 1st critical. The flow starts to go supersonic but then passes through a normal shock. After the shock, conditions are subsonic and the diverging section operates as a diffuser.

17. A pressure plot for this case is shown. The shock will locate itself in a position such that the pressure changes that occur ahead of the shock, across the shock, and downstream of the shock will produce a pressure that exactly matches the receiver pressure.

18. Thus, as the receiver pressure is lowered more, the shock will move towards the exit.

19. Eventually, the shock is located at the exit plane and this condition is referred to as the "second critical." Note that inside the nozzle conditions are exactly the same as 3rd critical or the design operating condition. However, immediately outside the nozzle we have subsonic flow after the normal shock.

20. If the receiver pressure is between 2nd and 3rd critical a normal shock is too strong to match the imposed pressure conditions and thus a weaker oblique shock takes place just past the exit. This condition is called "overexpansion" as the flow reaches a pressure inside the nozzle below that of the receiver.

21. In this Schlieren picture of an overexpanded nozzle we can also see the complicated pattern of expansion and compression waves after the initial oblique shocks . . .

22. If the receiver pressure is below that for 3rd critical operation then an expansion must take place outside the nozzle. Operation in this mode is called "under expansion" since the flow cannot expand to a low enough pressure inside the nozzle.

23. Here we again note the repetitive wave pattern following the initial expansion . . . . .

24. In the experiment you will attempt to verify the different regimes of operation for a converging-diverging nozzle.

25. The system is fed by compressed air which is stored in a large tank outside the building. The air passes through a regulating valve and into a plenum chamber, where its velocity is very small. From here the air enters the converging-diverging nozzle and exhausts to the atmosphere.

26. Here we see a photo of the valve, plenum, and nozzle . . .

27. In this close up we see the two-dimensional converging-diverging nozzle. Its front and back are made of glass which permits visualization of the flow field within the nozzle. Notice that there is a section of about 2-3/4 inches in length at the exit which forms a constant area extension to the nozzle. The exit area is one inch square. Various nozzle blocks are available to produce flow at different Mach numbers. The exact contour of the nozzle is given in a separate handout.

28. All flows will be photographed using a standard Schlieren system.

29. Pressures are measured with standard heise gauges.

30. From the nozzle area ratio you can predict the theoretical exit Mach number at design operation. This can be checked experimentally by at least three different methods.

31. First, one can determine the ratio of static to stagnation pressure at the exit. The static pressure is taken from a wall tap near the outlet and the stagnation pressure is assumed to be equal to that at the inlet.

32. With this ratio of static to total pressure, a quick check in the isentropic flow tables reveals the Mach number.

33. A second method makes use of small waves which are generated by the surface irregularities along the wall. These waves form at the characteristic Mach angle.

34. The angle can be measured from a Schlieren photo and the Mach number readily determined. .

35. The final method consists of inserting a pitot probe into the exit jet.

36. A detached shock will form ahead of the probe and the probe will indicate the stagnation pressure after the shock. A typical entry in the normal shock tables is the ratio of this total pressure to the static pressure ahead of the shock.

37. Undoubtably, the Mach numbers determined from your measurements will not exactly agree with the theoretical Mach number predicted by the nozzle area ratio.

38. Much of the discrepancy can be attributed to the boundary layer which forms in the diverging section of the nozzle. This makes the effective area ratio smaller than that formed by the physical walls.

39. Also, recall that a constant area section is attached to the nozzle exit. Flow losses will occur here which will affect your results.

40. There are a number of other studies which can be made with this same equipment.

41. The glass wall of the nozzle can be replaced with an instrumented plate permitting the pressure distribution throughout the nozzle to be recorded. This can be compared to theory for various modes of operation . .

42. By removing one side of the extension a biased, or non-symmetrical exit flow results. This simulates typical nozzles used in many turbines.

43. Before you enter the lab you should carefully study the written handout. Be familiar with the calculations that must be made so that you know what data to take. When you fully understand the experiment, examine the laboratory set up.

44. Design a data sheet before starting the experiment. This should not only contain columns for all data taken for each run, but also should contain an appropriate title together with any additional information taken at the time of the experiment. Be sure to include the units for all measurements.

45. You are cautioned that this free jet is extremely noisy and proper ear protection must be worn. Communication is

very difficult during the experiment, so plan ahead. Make certain everyone in your lab group knows their job.

46. In summary, we have reviewed the various operating regimes of converging-diverging nozzles. The experimental apparatus has been described along with three methods of determining Mach number . . Finally, some helpful suggestions were made on organizational procedures. (Start background music).

47. As with any experiment, this is your chance to learn some valuable laboratory techniques and compare your experimental results with those predicted by theory. (Increase volume of background music).

48. (Schwikert-Zorro Production slide).

49. (Blank - Continue music).

CONVERGING-DIVERGING NOZZLES

Slide List

1. Blank.
2. Target Slide.
3. Diagram of Converging-Diverging Nozzle.
4. Schlieren photo of Matched Flow.
5. Schlieren photo of Underexpanded Flow.
6. "The Department of Aeronautics Presents."
7. "Converging-Diverging Nozzles."
8. List of Objectives.
9. Diagram defining Throat and Exit Areas.
10. Diagram defining Inlet Stagnation and Receiver Pressures.
11. Graph of Pressure Ratio vs. Nozzle Station (No Flow).
12. Same as Slide #11 plus Subsonic Line.
13. Same as Slide #12 plus another Subsonic Line.
14. Same as Slide #11 plus 1st Critical Line.
15. Same as Slide #11 plus 3rd Critical Line.
16. Diagram showing Normal Shock in Nozzle.
17. Same as Slide #11 showing Normal Shock Pressure Recovery Line.
18. Same as Slide #17 showing another Normal Shock Pressure Recovery Line.
19. Same as Slide #18 showing 2nd Critical Line.
20. Same as Slide #11 showing Overexpanded Pressure Line.
21. Schlieren photo of Overexpanded Flow.
22. Same as Slide #11 plus Underexpanded Pressure Line.

23. Schlieren photo of Underexpanded Flow.
24. "Apparatus."
25. Block Diagram of Nozzle Experimental Set Up.
26. Photo showing Nozzle, Plenum, and Valve.
27. Close-Up photo of Nozzle including Extra Nozzle Blocks.
28. Photo of Schlieren System.
29. Photo of Pressure Gauges..
30. "Mach Number Determination."
31. Same as Slide #30 plus "Pressure Ratio."
32. Diagram showing P/P_t and Isentropic Tables.
33. Same as Slide #31 plus "Wave Angle."
34. Schlieren photo showing Mach Waves.
35. Same as Slide #31 plus "Pitot Probe."
36. Diagram of Pitot Probe and Detached Shock.
37. "Reasons for Discrepancies."
38. Photo of Boundary Layer.
39. Photo of Close-Up of Constant Area Section of Nozzle.
40. "Other Studies."
41. Photo of Nozzle Block containing Pressure Taps.
42. Photo of Nozzle Block with One Extension removed.
43. "Procedures."
44. Data Sheet.
45. Photo showing Three Men taking Data.
46. Summary of Program.
47. Photo of Gas Theory Book and Experimental Data.
48. "A Schwikert-Zorro Production."
49. Blank.

APPENDIX D

QUESTIONNAIRE ON SLIDE-TAPE BRIEFINGS (September 1974)

The slide-tape programs that were shown during the 3851 laboratories are the result of an ongoing thesis project. Considerable time and effort has gone into the preparation of these programs and it is our desire to continually assess their worth. Your cooperation in completing this questionnaire as soon as possible will be appreciated. (This will not have any impact on your grade but consider completion of this questionnaire a requirement of the Lab.) Please return to Prof. Zucker's mail box in the Aero Department Office.

1. To refresh your memory, the following lists the presentations that you saw:

    A. The Aerolab Low Speed Wind Tunnel (Details of NPS Tunnel)
    B. Operating Instructions for the Aerolab Tunnel.
    C. Introduction to Low Speed Wind Tunnels (History, Classification, etc.)
    D. Airfoil Performance by Pressure Distribution.
        i. Part I - Introduction
        ii. Part II - Data Reduction
    E. Wind Tunnel Balances (Mountings, Linkage Systems, etc.)
    F. The Aerolab "543" Wind Tunnel Balance (Details of NPS Balance)

2. Do you feel that there is a need for presentations of this type?

    86% ☐ Yes 3% ☐ No 11% ☐ No strong opinion

3. Handouts were given you which covered the same material. Were these handouts helpful?

    94% ☐ Yes 3% ☐ No 3% ☐ No strong opinion

4. This question concerns the duplication of material in the handout and the presentation.

    ☐ I would rather see the slide-tape presentation only.
    3% ☐ I would rather read the handout only.
    86% ☐ I would like to have both the handout and the presentation.
    11% ☐ I would like some other arrangement. Indicate what.

Questions 5 through 8 pertain to the programs which covered the experiment on pressure distribution over an airfoil.

5. Do you feel that the slide-tape presentation contributed to an understanding of the lab and its objectives?

97% ☐ Yes 3% ☐ No ☐ No strong opinion

6. Were you better equipped to go into the lab and perform this experiment?

86% ☐ Yes ☐ No 14% ☐ No strong opinion

7. Should all experiments be preceded by a briefing of this type?

83% ☐ Yes 8% ☐ No 9% ☐ No strong opinion

8. Part II was an attempt to cover a dull subject; i.e., the derivation of the equations required and the procedures to reduce the data. Did this satisfactorily accomplish its purpose?

47% ☐ Yes 19% ☐ No 33% ☐ No strong opinion

9. It has been suggested that once sufficient Slide-Tape Briefings have been prepared, the lab could be run on a "self-paced" basis. That is, students would sign up (in groups of two or three) for any time during the week that is convenient. They could view the slide-tape presentations and then perform the experiment. A technician would be in the general vicinity of the equipment for immediate assistance. An instructor would be assigned (but not present in the lab) for further consultation.

   (a) Would the Slide-Tape Briefings plus the written handouts be sufficient for self-paced laboratories?

   77% ☐ Yes 23% ☐ No

   If you answered no, what additional aids do you suggest?

   (b) WHAT WOULD YOU THINK OF THIS TYPE OF OPERATION?

APPENDIX E

QUESTIONNAIRE ON SLIDE-TAPE BRIEFINGS (January 1975)

The tape-slide programs that were shown during the 3851 laboratories are the result of an on going thesis project. Considerable time and effort has gone into the preparation of these programs and it is our desire to continually assess their worth. Your cooperation in completing this questionnaire as soon as possible will be appreciated. (This will not have any impact on your grade but consider completion of this questionnaire a requirement of the Lab.) Please return to Prof. Zucker as soon as possible.

To refresh your memory, the following lists the presentations that you saw:

A. The Aerolab Low Speed Wind Tunnel (Details of NPS Tunnel)
B. Operating Instructions for the Aerolab Tunnel.
C. Introduction to Low Speed Wind Tunnels (History, Classification, etc.)
D. Wind Tunnel Calibration
E. Wind Tunnel Turbulence Calibration
F. Airfoil Performance by Pressure Distribution
    Part I - Introduction
G. Airfoil Performance by Pressure Distribution
    Part II - Data Reduction
H. Wind Tunnel Balances (Mountings, Linkage Systems, etc.)
I. The Aerolab "543" Wind Tunnel Balance (Details of NPS Balance)

1. Did the presentations sufficiently prepare you to conduct the experiments?

50% ☐ Yes 50% ☐ No ☐ No Opinion

If your answer is No please give details.

2. Handouts were given to you which covered the same material as the slide-tape programs. Were these handouts necessary?

100% ☐ Yes ☐ No ☐ No Opinion

3. This question concerns the duplication of material between the printed handout and the slide-tape presentation.

☐ I would rather see the slide-tape presentation only.

☐ I would rather read the handout only.

100% ☐ I would like to have both the handout and the presentation.

☐ I would like some other arrangement. Indicate what

4. Did you encounter any problems during the experiments that required an instructor?

50% ☐ Yes 50% ☐ No

If your answer is yes please give details.

5. Would you recommend that other lab courses be taught using slide-tape presentations?

80% ☐ Yes 20% ☐ No ☐ No Opinion

6. Do you feel that the slide-tape presentations contributed to an understanding of the lab and its objectives?

100% ☐ Yes ☐ No ☐ No Opinion

7. Organizational and Procedural tips were given in some of the lectures.

a. Did these help you in conducting the experiment?

100% ☐ Yes ☐ No ☐ No Opinion

b. Can you think of any other tips that should be included?

In questions 8 and 9 be as specific as possible by referring to presentations by the letter opposite listing on first page. For example: opposite "Too short" mark F if you feel that is appropriate.

8. The slide-tape presentations were

H(1)	Too long and drawn out.
D(1)G(2)H(1)I(1)	Too short, didn't cover the subjects.
A-C(10)D(8)E(4)F(9) G(8)H(8)I(9)	About right.
D(1)E(1)F(1)	No opinion.

9. Do you feel the presentations contained

H(1)	Too many slides, they detracted from the script.
D(1)G(2)H(1)J(1)	Not enough slides to illustrate important points.
A-C(10)D(8)E(9)F(9) G(8)H(8)I(9)	About right.
D(1)E(1)F(1)	No opinion.

10. The following techniques were used in designing the slides used in the slide-tape programs.

White letters on a solid colored background,
Black letters on a solid colored background,
White letters on colored background with texture. (In presentation E)

a. Was any letter/background combination distracting or difficult to view?

b. Did you prefer any letter/background combination?

11. Is there anything that you particularly liked/disliked about the slide-tape programs?

12. Do you have any suggestions to improve the slide-tape programs?

13. It has been suggested that once sufficient slide-tape briefings have been prepared, the lab could be run on a self-paced" basis. That is, students would sign up (in groups of two or three) for any time during the week that is convenient. They could view the slide-tape presentations and then perform the experiment. A technician would be in the general vicinity of the equipment for immediate assistance. An instructor would be assigned (but not present in the lab) for further consultation.

    a. Would the slide-tape briefings plus the written handouts be sufficient for self-paced laboratories?

    100% ☐ Yes ☐ No

    If your answer is no, what additional aids do you suggest?

    b. Would you like/dislike taking the lab on this system? Comment.

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